UNITED STATES DEPARTMENT OF AGRICULTURE

In cooperation with the
Pennsylvania State College

DEPARTMENT BULLETIN No. 1281

Washington, D. C. December, 1924

RELATIVE UTILIZATION OF ENERGY IN MILK PRODUCTION AND BODY INCREASE OF DAIRY COWS

By

J. AUGUST FRIES, Assistant Director, WINFRED WAITE BRAMAN and DONALD C. COCHRANE, Associates in Animal Nutrition, Institute of Animal Nutrition of Pennsylvania State College

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1924

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RELATIVE UTILIZATION OF ENERGY IN MILK PRODUCTION AND BODY INCREASE OF DAIRY COWS

By J. August Fries, *Assistant Director*, Winfred Waite Braman and Donald C. Cochrane, *Associates in Animal Nutrition, Institute of Animal Nutrition of Pennsylvania State College*

CONTENTS

This bulletin covers the first of a series of cooperative experiments [1] with the respiration calorimeter on the metabolism of dairy cows, in accordance with an agreement between the Dairy Division, Bureau of Animal Industry, United States Department of Agriculture, and the Institute of Animal Nutrition of the Pennsylvania State College, and as recorded in the program of work of the department for the fiscal year 1915–16. Previous work with the respiration calorimeter had been with steers, and although much remains to be done in connection with the fundamental problems of feeding for meat production, the increasing importance of the dairy industry of the United States led the late H. P. Armsby, then Director of the Institute of Animal Nutrition, to plan this series of experiments with milk cows.

In connection with this report of the first experiment the general scheme as outlined by Director Armsby is given in full as follows. Although changes in experimental procedure have been made as our knowledge of the problem has increased, the project plan has been

[1] To Director H. P. Armsby belongs the credit for the planning and inception of the experimental program. For the execution of the plan of experiment the responsibility rested largely with the senior writers but the success of this venture was in no small measure due to the faithful work of K. K. Jones, J. W. Park, J. E. Mensching, J. E. Isenberg, and E. W. Schmidt, and to other members of the staff of the institute, who assisted the writers in various capacities.

The writers also desire to express their appreciation to E. B. Forbes, director of the institute, for his kindly criticism and suggestions which have been invaluable in the preparation of these data for publication.

followed faithfully during the entire series of experiments extending over a period of seven years.

GENERAL SCHEME FOR EXPERIMENTS WITH RESPIRATION CALORIMETER ON MILK PRODUCTION

Animals to be used.—Since considerable work on cattle has already been done with the respiration calorimeter, and since cows constitute the commercial source of milk, it would be most desirable to experiment with those animals. If, however, this is deemed impracticable, because of the difficulty involved in the satisfactory collection of the excreta of cows, necessitating the employment of watchmen at very considerable expense, it is thought that milk goats will, on the whole, be fairly satisfactory as experimental animals, at least for preliminary investigations. If they are used it is proposed to employ a form of metabolism cage devised by Bowes, which permits the separation and collection of the feces and urine with comparatively little oversight.

General problem.—It is proposed to determine the total energy of the feed consumed by milking animals, the losses of energy in the excreta, the expenditure of energy consequent upon the consumption of feed, and, by difference, the net energy of the feed, in the same general manner as in experiments on steers. Furthermore, however, it is proposed to determine the distribution of this net energy of the feed between the two possible forms of production, viz, fattening, or milk secretion, and the effect upon it of the quantity of the feed as well as of other factors.

Lines of experiment.—The following general lines of experimental work are outlined:

1. To determine the maintenance requirement of the dry animal.
2. Feed a moderate ration and, by means of successive respiration-calorimeter experiments, trace the variations in the distribution of net energy between milk production and body gain with advancing lactation. In this way, it is hoped to determine the quantitative relation between the two forms of production.
3. Study the effect of varying amounts of the same combination of feeding stuffs in increasing the milk production on the one hand and the body gain of the animal on the other hand.
4. Study the effect upon milk production and body gain of substituting protein for carbohydrates or vice versa in rations otherwise identical.

SCHEME FOR EXPERIMENTS WITH DAIRY COWS

Later Director Armsby prepared the following outline:

The general problem proposed is to determine in terms of energy the efficiency of the cow as a mechanism for converting feeding stuffs into milk.

The efficiency here considered is what may be called the net efficiency; that is, the percentage of the amount of feed energy supplied *in excess of that required for maintenance* which is recovered in the milk. The net efficiency, as thus defined, constitutes one of the factors of the economic efficiency, but the latter necessarily varies with the proportion of the total feed which is available for productive purposes. Otherwise expressed, the problem is to determine the net energy values of feeding stuffs for milk production. This problem might be attacked in two ways.

1. By the direct determination of the net energy values of single feeding stuffs by substantially the methods used in previous investigations upon beef production. This method, however, would be somewhat tedious and would involve more or less correction of the results, upon the basis of average figures, for any fattening of the animals which might occur.
2. By determining upon identical animals the relative availability of the energy of one or a few standard feed mixtures for fattening, on the one hand, and for milk production on the other, and applying the ratio thus determined to the data already available for utilization in fattening.

The second of these two methods appears to promise more immediate, even if somewhat approximate results, and is the method which it is proposed to follow.

The general plan is to make in a first season two or three respiration-calorimeter experiments upon dry cows receiving different amounts of the standard feed mixture by a comparison of which the maintenance requirements and the net utilization in fattening by the individual animals may be determined.

Incidentally the basal katabolism of the animals as computed by a comparison of the two periods on different amounts of feed is to be compared with katabolism

as measured directly by the heat production after a longer or shorter period of fasting in order to ascertain whether it is possible to determine the basal katabolism of cattle by a single determination of the heat production in what corresponds to the "post-resorptive" state in man.

Then, in a second season, two or three respiration experiments are to be made upon the same cows when in milk at different stages of lactation and on different amounts of the standard feed mixture. From the results is to be computed the utilization of the energy remaining for milk production after the demands for maintenance and for any fattening which may occur have been allowed for on the basis of the results obtained upon that identical animal during the first season.

Circumstances beyond the control of the writers prevented taking up the experimental work in the order outlined, and the experiment here reported takes up only the second problem under the head, "Lines of Experiment," "Feed a moderate ration and by means of successive respiration-calorimeter experiments trace the variations in the distribution of net energy between milk production and body gain with advancing lactation. In this way it is hoped to determine the quantitative relation between the two forms of production."

CHANGES IN TECHNIC

Before the experiments with cows could be outlined in detail a number of problems involving changes in the technic of he former steer experiments had to be studied. The main question, of course, involved a separate collection of the feces and urine in order that the digestibility of the ration might be determined. The method of milking the animal while in the respiration calorimeter and the collection of the excreta in that apparatus also confronted the writers.

Various devices for the automatic separation of urine from feces in the digestion stalls were tested and discarded, and it was necessary to depend upon a watchman stationed behind the animals.

The problem of milking likewise could not be solved by any apparatus; and since reconstruction of the respiration calorimeter was out of the question, it was necessary to have a man enter the chamber to attend to the milking and to apply the necessary corrections to the ventilation and to the heat as measured.

The third problem, and perhaps the most perplexing, was to provide a means for the collection of the excreta in the respiration calorimeter. Since in this apparatus the feces and urine can not be allowed to drop on the floor, or remain exposed to the ventilating air current, it is necessary to use a duct to direct the excreta into a proper receptacle. This duct must of necessity be comparatively light and comfortable for the wearer in order that the animal may lie down and get up without difficulty; it must not press upon the udder or milk veins or interfere with the milking; and it must fit closely so as not to be disarranged by the movement of the animal. One of he writers (Fries) devised and made the ducts, a description and sketch of which follows.

The shape and method of attachment of the duct for collecting the excreta are illustrated in Figure 1. The duct was made of heavy muslin, which was reenforced at the top edge of the side flaps along the back with leather straps, and at the lower edge by a double hem. It weighed about 1.9 kilograms, and the entire collecting apparatus, including collar and attaching straps, weighed 5.9 kilograms. At *B* is a ring, 8 inches in diameter and three-fourths inch wide made of steel clock spring. To this ring the upper and lower portions of the

muslin are securely fastened. From *B* the duct is 7 inches in diameter practically all the way down to the end. A second ring, 7 inches in diameter, made of a somewhat lighter clock spring, is placed about 25 inches below *B* at *D*. Attached to this latter ring are several small rings to which stays may be fastened. As indicated in the sketch, from *A* to *C* is a slit so that *A C B* forms a flap of the muslin. The two side flaps are held together over the back by short leather straps by which the openings may also be regulated to conform to the shape of the animal. From *A* to *E* and down to the ring *B* the duct is enlarged to such shape and size that the tail, which is kept within the duct, can be raised during the voiding of the excreta. The side flaps *A C B* start on *B* about 6 inches apart and by means of these the ring and duct are held against the body at a place where they do not interfere with the defecation or movements of the animal and which permit the urine and feces to be conducted without loss.

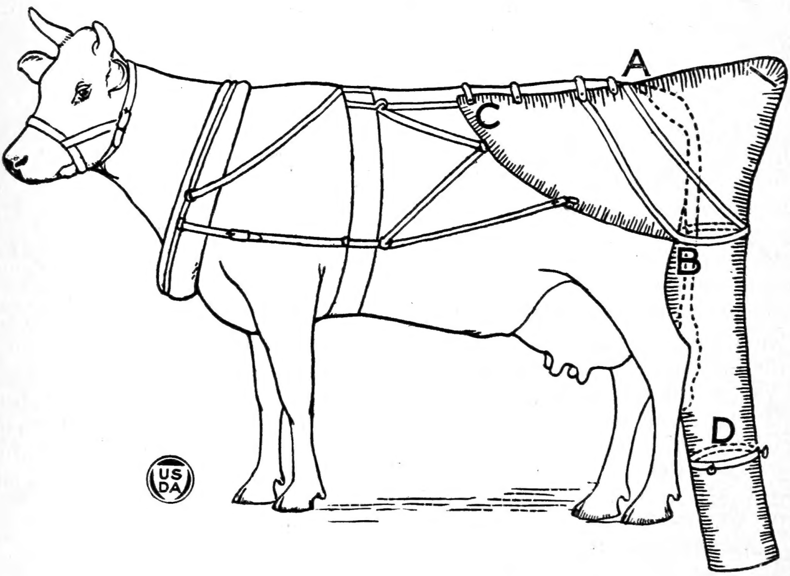

FIG. 1—Duct in position on cow.

This duct will remain in place on the animal without using straps between the legs. The duct received a coating of linseed oil to make it waterproof. This waterproofing failed to satisfy the requirements, and in subsequent experiments a loose lining of thin waterproof "stork sheeting" was used. With this modification the duct has been very satisfactory.

PLAN OF THE EXPERIMENTS

The general plan for the experiments with cows was the same as that followed in the experiments with steers, namely, to feed a given ration for a definite length of time, not less than three weeks, this time being divided into a preliminary feeding period and the so-called digestion period, usually of nine days' duration, during which the visible excreta as well as the milk were collected for analysis. The animals were watered daily as soon as they had eaten the morn-

ing feed. The work was carried on by the aid of the respiration calorimeter, and at some time during the last 10 days of each period, the animal was placed in this apparatus so that CO_2, CH_4, and O_2 as well as the heat given off by the animal might be measured.

TABLE 1.—*Amounts of feeds and dates of periods*

Cow No.	Period	Daily feed		Dates of the periods		
		Hay	Grain	Feeding begun	Calorimeter test	Collection of urine and feces
		Kg.	*Kg.*			
631	I	3.280	4.900	Dec. 8	Jan. 12	Jan. 14–22.
	II	3.280	4.900		Mar. 8	Mar. 10–18.
	III	3.280	4.900		Apr. 19	Apr. 21–29.
615	I	3.364	5.080	Dec. 8	Feb. 9	Feb. 11–19.
	II	3.364	5.080		Mar. 22	Mar. 24–Apr. 1.
	III	3.364	5.080		May 3	May 5–13.
579	I	3.730	5.590	Jan. 24	Feb. 23	Feb. 25–Mar. 4.
	II	3.730	5.590		Apr. 5	Apr. 7–15.

ANIMALS

The subjects of this experiment were of quiet disposition and fair productive capacity. The choice of these particular individuals was determined in large part by the fact that they were free from tuberculosis, the general presence of this disease having been discovered in the college herd not long before the beginning of this research. After the conclusion of the tests here reported these cows also became tuberculous, and were sacrificed before the maintenance requirements could be determined. The three cows were numbered 579, 615, and 631 and are so designated throughout this bulletin.

Cow No. 579 was a grade of seven-eighths Guernsey blood, born November 7, 1911. Her first calf was dropped on October 5, 1914, and her second on November 25, 1915. She was not bred after the second calving.

Cow No. 615 was also a grade of fifteen-sixteenths Guernsey blood, born October 22, 1912. She aborted with her first calf May 1, 1915, and with her second calf (a 2-months fetus) February 20, 1916.

Cow No. 631 was a grade Jersey, bought with age and breeding unknown, and supposed to have been dropped in 1906. She calved April 11, 1915, and was due to calve again about May 27, 1916.

RATIONS

All the animals were fed rations consisting of the same feeding stuffs mixed in the same proportions throughout the experiment. The quantity for each animal was adjusted so as to be sufficient at the outset to support milk production but not to cause any considerable gain of body tissue, and remained unchanged throughout the experiment. It was anticipated that as the milk production decreased with advance in the period of lactation the surplus feed would be utilized for body gain in place of milk, thus affording a means of comparing the relative utilization of the feed for the two purposes. To insure complete consumption a minimum ratio of hay to grain was fed. The ration fed was identical with that in use at the same time in the dairy husbandry department of the college, the grain mixture being composed of wheat bran, yellow corn meal, ground

oats, and old-process linseed meal, all of good quality. The hay was average quality alfalfa grown in Colorado, nicely cured, fairly uniform in color, and contained a normal proportion of leaves.

The hay was cut into inch lengths by means of a silage cutter, with the blower removed to prevent the loss of the finer leaf particles. This cut hay was spread in a uniform layer on a barn floor, and carefully shoveled over a few times, taking special pains to distribute the fine material with the coarse as evenly as possible. It was afterwards transferred to large sacks and placed in a storage bin.

The hay was weighed out for 14 days at a time including the digestion period, and when possible for more than one animal at the same time. A sufficient quantity of the cut hay was carefully mixed on the loft floor, the quantity for each feed weighed in a metal receptacle, transferred to dust-proof cotton bags, and stored until needed.

The sample for chemical analysis was prepared from small amounts withdrawn at each weighing. When the weighing of the rations was completed this sample material was chopped finer in a meat chopper, then carefully mixed and quartered. This process of mixing and reduction was repeated until a sample of the desired size was obtained.

The sample was then taken to the laboratory for air-drying and grinding. The finely ground air-dry samples were kept in glass-stoppered jars which, as a precaution against moisture change, were sealed with soft wax.

The grain mixture consisted of:

	Parts
Wheat bran	300
Ground oats	300
Corn meal	300
Linseed meal (old process)	100

To each 1,000 parts of this mixture were added 2.22 parts of dairy salt. From this mixture the feeds were weighed out for the preliminary periods. For the digestion periods and for the five days preceding them, the feeds were weighed out from the separate components and 5 grams of fine dairy salt were added to each of the half-day rations.

DIGESTION EXPERIMENTS

The ration of each cow remained unchanged throughout the whole investigation. The feeding period for cow No. 631 was 143 days; for No. 615, 157 days; and for No. 579, 82 days.

The spacing of the digestion experiments was fixed by the time of the respiration-calorimeter tests which could be carried on only biweekly. During these respiration-calorimeter tests the urine and feces could not be collected separately; therefore, in this experiment, the calorimeter test was followed by a 9-day period for the separate collection of the urine and feces.

For this collection of excreta the animal was taken to the dairy barn where the excreta were collected by a man stationed behind the animals.

WEIGHING AND SAMPLING EXCRETA

Each voiding of urine was transferred to a 20-liter bottle, and of feces to a covered galvanized-iron box. At the end of each 24 hours the excreta were weighed. The urine was then well mixed and a sufficient quantity taken to the laboratory for the making up of the 9-day composite sample as well as for certain determinations made on the fresh daily sample. The aliquot weighed out daily for the

composite was one-twentieth of the total, and was preserved by the addition of chloroform to the storage bottle. The feces were weighed, immediately dumped on a large zinc-covered mixing board, mixed quickly, quartered, and sampled, the sample being placed in covered cans which were taken to the laboratory for the preparation of the composite samples. These composite samples were made up of one-fortieth of the total feces, and were kept in duplicate in covered zinc cans of about 3 liters capacity. The lid was made air-tight by a broad rubber band over the crack, and a few drops of carbon bisulphide were added from time to time as a preservative.

WEIGHING AND SAMPLING MILK

The milk, after weighing, was well mixed by pouring from one bucket to another. A sample was preserved by the addition of 1 cubic centimeter of 40 per cent formalin per liter.

The morning milk was combined with the evening milk in the proportion of their respective weights to form the daily sample. From these daily samples the aliquots for the composites were weighed out, one twenty-fifth of the total being so preserved. The composite samples were weighed out in duplicate. A separate portion of each of the daily milk samples was kept for nitrogen estimations. All weights of urine, feces, and milk were taken on scales weighing accurately to within 5 grams. The aliquots were weighed on balances accurate to within 0.01 gram.

THE RESPIRATION CALORIMETER

Apparatus.—The respiration calorimeter, as its name implies, is an apparatus for the measurement of the animal respiratory products and the heat emission. This particular apparatus is an open-circuit Atwater and Rosa respiration calorimeter modified so as to be suitable for work with cattle instead of men. A detailed description of its construction and operation has been published by Atwater and Benedict (*1*)[2] and by Armsby (*2*). It consists of a copper-lined chamber containing a comfortable stall large enough for a medium-sized cow, the animal being able to lie down or stand at will.

Gases.—The doors close tight against rubber gaskets and the ventilation is maintained by means of a pump which draws a constant current of air through the chamber and measures the volume at the same time. This ventilating air current is sampled and analyzed as it enters and leaves the chamber and in this way the gases added by the animal are determined.

Heat.—The heat removal and measurement are accomplished by means of a current of cold water circulating through a coil of copper tubing within the chamber. In this experiment the gas and heat measurement covered 24 hours, subdivided into two 12-hour periods.

Calorimeter period.—The cow was placed in the calorimeter chamber at about 1 p. m. At 6 p. m. the experiment began, ending the second day following at 6 p. m. While the animal was in the respiration calorimeter no attempt was made to keep the urine and feces separate, and the total excreta were weighed and sampled at the end of each 24 hours.

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[2] Figures in italics in parenthesis refer to Literature Cited, page 33.

Live weight.—The cow was weighed just before entering the respiration calorimeter and immediately after leaving it at the end of the experiment.

Feed and water.—The animals were fed at 6 o'clock morning and evening through a lock trap which is an integral part of the apparatus. After the animal had finished the morning feed, water was offered in a specially constructed basin. The details of these operations have been described in previous publications of the Pennsylvania Institute of Animal Nutrition.

Temperature.—The rectal temperature of the animal was taken with a clinical thermometer about one hour before the beginning of the experiment and also at the end of the experiment.

Milking.—The cow was milked twice daily, at 4.30 morning and evening, by the same person. To accomplish this the main door of the apparatus was opened and closed while the milker stepped into and out of the apparatus. The presence of the man in the chamber necessitates a correction which has been taken into account.

Error due to opening the respiration chamber.—Since the ventilation current is drawn through the chamber the loss of gases due to opening the door is less than it would be were the air forced through or were it stationary at normal pressure. However, since the temperature of the air in the chamber is usually several degrees centigrade lower than the room air, an outward flow of air naturally takes place at the opening of the doors. This loss can not be very large under these conditions; but, whatever it may be, no correction is applied and the error is carried throughout the experiment.

PREPARATION OF FEED AND FECES SAMPLES FOR ANALYSIS

A sufficient quantity of hay, grain, or feces samples to contain from 1.5 to 2 kilograms of dry matter was weighed out and placed on shallow, galvanized-iron pans and allowed to dry in a steam-heated drying-closet at from 55° to 65° C. When the samples had become thoroughly dry the pans were removed and placed on shelves in the grinding room for several days in order that the material might come to approximately normal moisture content at the room temperature. Just before the grinding, the pans with the samples were weighed and the loss in weight termed "loss on air drying." The material was then finely ground, being passed through the mill two or more times until the desired degree of fineness was obtained. This finely ground material was allowed to lie exposed to the air until cooled, then carefully mixed, transferred to glass-stoppered bottles, and sealed.

METHODS OF ANALYSIS

On the ground feed and feces samples, the usual feeding-stuff analyses were made; and the heat of combustion was determined by means of a bomb calorimeter. In general, the methods of analysis of the Association of Official Agricultural Chemists have been followed.

In the fresh feces "total nitrogen" was determined by the König method.

In the fresh composite urine the specific gravity, total nitrogen, and carbon were determined. For the energy determination about 5 grams of urine was weighed into a platinum capsule and dried in a

Hempel desiccator for two days; then a second charge was added and the capsule returned to the Hempel desiccator to remain until dry enough to ignite without the aid of any priming substance. The combustion in the bomb is complete when 20 atmospheres of oxygen is used.

In the daily composite milk samples of the intermediate periods, the specific gravity and fat were determined, the latter by the Babcock method. Carefully calibrated bottles were used, the measured milk charges being weighed on an analytical balance. In the daily composite milk samples of the digestion and calorimeter periods total nitrogen and fat (by the Babcock method) were determined, and in the composite sample of each period determinations of specific gravity, fat, nitrogen, carbon, and energy were made.

Samples of the daily feces were analyzed for total moisture.

Since this is the first experiment ever reported in which the energy output of the milking animal was directly determined, and since the maintenance requirement of the cows was not determined, such an exhaustive study of the results is not submitted as will be possible when the data of subsequent experiments of this series shall have become available. At present, therefore, the more prominent results only will be pointed out, placing on record the experimental data with the hope that later results may shed additional light on the subject and serve to confirm the conclusions from this study.

LIVE WEIGHTS AND RATIONS

The live weights given in Table 2 are the average of nine daily weighings taken before watering and the same time of the day. At the time of weighing, small amounts of feed were sometimes noticed in the feed box; but these, with a few exceptions, were eaten after the animal had been watered. In the same table is recorded the total weight of daily feed. The feed was divided into two equal portions, the grain and hay being fed together at the specified hour.

TABLE 2.—*Average daily weights before watering, and weights of daily rations*

Cow No.	Live weight			Daily feed		
	Period I	Period II	Period III	Alfalfa hay	Grain mixture	Salt
	Kilograms	*Kilograms*	*Kilograms*	*Kilograms*	*Kilograms*	*Grams*
631	334.3	360.6	390.4	3.280	4.900	10
615	361.8	366.1	368.9	3.364	5.080	10
579	367.2	371.8		3.730	5.590	10

Cows 615 and 579 showed a slight tendency to gain in weight with the advance in the lactation period. Cow 631 was about dry in period II and her increase in weight is due in part to the rapid development of the fetus at her advanced stage of pregnancy.

COMPOSITION OF FEED AND FECES

The alfalfa hay, grain mixture, and the feces of the various periods were subjected to the customary feeding-stuff analyses, as reported in Table 3. The heat of combustion was also determined, the data being computed to dry matter.

Particular attention is called to the loss of nitrogen on drying the dung by itself. This same loss also occurs in the dung-and-urine

100177—24†——2

mixture; and for that reason the nitrogen determined on the fresh material by König's method is used throughout the computations.

APPARENT DIGESTIBILITY

The detailed data used in computing the apparent digestibility of the rations will be found in the appendix. In these tables the salt has been added to the dry matter. The digestion coefficients of the feed have been collected for comparison, and are recorded in Table 4.

TABLE 3.—*Composition of dry matter of feed and feces*

Substance	Cow No.	Period	Dry matter	Ash	Protein	Nonprotein	Crude fiber	Nitrogen-free extract	Ether extract	Total nitrogen	Protein nitrogen	Carbon	Energy per gram
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Calories*
Alfalfa hay	631, 615	I, I	88.970	8.159	14.713	2.698	27.609	44.320	2.501	2.928	2.354	45.748	4,435.77
	631, 615, 579	II, II, I	89.727	8.217	14.069	2.975	27.465	44.725	2.549	2.884	2.251	45.760	4,433.11
	631, 615, 579	III, III, II	90.315	8.582	14.625	3.177	27.411	43.546	2.659	3.016	2.340	45.769	4,440.52
Grain mixture	631, 615	I, I	87.556	4.471	13.947	.400	8.187	68.139	4.695	2.465	2.380	46.145	4,549.46
	631, 615, 579	II, II, I	86.675	4.384	13.918	.479	8.248	68.093	4.830	[1] 2.477	2.375	46.055	4,548.37
	631, 615, 579	III, III, II	85.940	4.370	13.771	.653	8.008	68.581	4.580	2.489	2.350	46.092	4,544.67
Feces	631	I	18.295	10.707	11.781	1.208	32.886	40.499	2.919	[2] 2.405; 2.142	1.885	46.976	4,674.55
	631	II	18.163	11.156	11.275	1.556	32.790	40.540	2.683	[2] 2.329; 2.135	1.804	46.426	4,612.25
	631	III	17.644	11.279	11.963	1.053	32.976	39.959	2.770	[2] 2.346; 2.138	1.914	46.423	4,601.24
	615	I	17.421	10.046	12.006	.978	32.106	42.409	2.455	[2] 2.520; 2.129	1.921	46.954	4,651.40
	615	II	18.132	10.043	10.400	2.421	30.943	43.425	2.763	[2] 2.410; 2.179	1.664	46.969	4,644.12
	615	III	17.776	10.222	11.994	.926	33.900	40.535	2.423	[2] 2.481; 2.116	1.919	46.796	4,627.26
	579	I	16.249	10.878	11.325	1.711	32.853	40.649	2.584	[2] 2.572; 2.176	1.812	46.499	4,617.21
	579	II	16.404	10.389	11.200	2.045	33.102	40.787	2.477	[2] 2.566; 2.227	1.792	46.686	4,608.75

[1] Average of the other two grain-mixture samples.
[2] Nitrogen in fresh feces by König method, computed to dry matter. In the grain mixtures the protein was obtained by multiplying protein-nitrogen by the factor 5.86, and the nonprotein nitrogenous matter by using the factor 4.7.

Table 4 shows a very close agreement between the apparent digestibility of dry matter on a percentage basis, and also in terms of energy. Cow 579 shows an apparent digestibility of the ration approximately 2 per cent higher than the other two cows.

The organic matter appears to be about 2.5 per cent more digestible on a percentage basis than in terms of energy. This difference is probably due to the fact that the ingredients as determined in the feces do not have the same composition as those in the feed. This is especially true of the crude fiber, which has a higher carbon content in the feces than in the feed. The feces invariably show a higher energy value per gram of dry matter than the feed.

The divergence of the coefficient of digestibility of protein with cow 615, period II, from the average, is unexplained; and since it is accompanied by an abnormally low figure for nonprotein nitrogenous matter it is probably due to some error of work. Both of these figures have been omitted from the average for this animal.

TABLE 4.—*Digestion coefficients (apparent digestibility—feed minus feces)*

Cow No.	Period	Dry matter	Organic matter: Dry matter	Organic matter: In terms of energy (calories)	Protein	Non-protein	Crude fiber	Nitrogen-free extract	Ether extract	Total nitrogen	Carbon
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
631	I	67.93	69.51	66.67	73.47	70.80	34.20	77.77	75.36	74.06	67.19
	II	66.80	68.59	65.93	73.19	65.52	32.34	76.97	77.12	70.70	66.39
	III	67.52	69.26	66.75	72.45	79.77	33.02	77.69	76.23	71.78	67.14
	True average	67.42	69.12	66.45	73.04	72.39	33.19	77.47	76.24	72.18	66.91
615	I	67.11	68.50	65.99	72.26	75.66	33.91	76.15	78.78	73.53	66.38
	II	67.90	69.26	66.84	[1] 76.09	[1] 47.97	38.09	76.18	77.24	73.50	67.14
	III	67.57	68.95	66.62	72.42	82.16	31.06	77.42	79.24	70.19	66.94
	True average	67.53	68.91	66.48	72.34	78.91	34.36	76.58	78.41	72.41	66.82
579	I	69.65	71.20	68.83	75.38	65.36	38.08	78.89	79.85	74.99	69.24
	II	69.09	70.47	68.32	75.47	62.64	36.01	78.34	79.78	74.55	68.57
	True average	69.37	70.84	68.57	75.43	64.00	37.05	78.62	79.81	74.77	68.90

[1] Omitted from the average.

In Table 5 the figures for the urine represent the average for nine days, except with cows 631 and 579, period I, in which cases the average includes but eight days because of an accident to some of the samples.

HAIR AND SCURF REMOVED BY BRUSHING

The daily growth and loss of hair plus the epithelial offal, or dandruff, may be considered either as a gain of substance together with other forms of production, or as an excretory product. Since in the dairy cow this material is not a desired product, is not accumulative on the animal, and can not, like protein and fat, be again metabolized as a nutrient either in or out of the animal body, it has seemed wisest to treat it as an excretum. The quantity and composition of this daily loss are found in Table 6.

MILK

The quantity and composition of the milk are given in Table 7.

TABLE 5.—*Average daily excretion of nitrogen, carbon, and energy in urine*

Cow No.	Period	Weight	Dry matter [1]	Total nitrogen [2]	Total carbon	Organic matter as energy
		Grams	*Grams*	*Grams*	*Grams*	*Calories*
631	I	6,540.6	586	105.41	163.58	1,583.8
	II	7,536.0	626	132.33	177.25	1,691.1
	III	7,141.7	530	117.98	154.55	1,431.7
615	I	6,131.8	512	94.98	138.82	1,323.4
	II	6,860.4	500	96.53	146.47	1,409.2
	III	6,970.0	393	99.70	150.55	1,406.3
579	I	6,867.5	544	101.88	151.63	1,487.2
	II	7,685.1	492	112.14	163.15	1,611.3

[1] The dry matter was computed from the charges of urine which were dried sufficiently for the combustion in the bomb calorimeter, but not absolutely dry They are, roughly, 5 per cent high.
[2] Average of the total nitrogen in the daily urine.

TABLE 6.—*Daily weight of hair and scurf removed by brushing*

Cow No.	Period	Dry matter	Nitrogen	Carbon	Organic matter as energy
		Grams	*Grams*	*Grams*	*Calories*
631	I	26.3	1.88	10.33	110.08
	II	18.7	1.34	7.34	78.27
	III	22.4	1.60	8.80	93.75
615	I	22.7	2.02	9.99	107.53
	II	20.6	1.84	9.06	97.59
	III	18.8	1.67	8.27	89.06
579	I	16.5	1.29	6.59	70.24
	II	20.6	1.61	8.23	87.70

Total dry matter not fat has been computed according to the formula:

$$\frac{\dfrac{\text{sp. gr.} - 1.0000}{\frac{1000}{4}}}{} + \frac{\text{per cent fat}}{5} + 0.14$$

To this the addition of the fat gives the total dry matter in the milk.

METHANE

The combustible gases escaping from the animal were determined in a continuous sample of air from the respiration-calorimeter chamber, which was first freed from carbon dioxide and water and then passed through a combustion tube, where by means of red-hot platinized kaolin the combustible gases were oxidized. The water and carbon dioxide thus formed were absorbed and weighed and from the weight of the carbon dioxide the methane was computed. The water determination, because of the long tubes and many rubber connections in the apparatus, is not considered so accurate as that of the carbon dioxide. The grams of methane per 100 grams of digestible carbohydrates (feed minus feces) have been computed, and these together with the other values for methane are recorded in Table 8.

In view of the fact that methane is a product of fermentation, the total quantity in the separate periods as well as the amount per 100 grams of digested carbohydrates was found to be remarkably uniform. The average amount per 100 grams of digestible carbohydrates for the eight periods of this experiment was 5.02 grams, whereas 4.5 is the general average from a large number of experiments made here and in Europe. The average amount of methane per day for the eight periods was 191.84 grams, or 267.6 liters under standard conditions.

TABLE 7.—*Amount, composition, and energy value of the daily milk*

Cow No.	Period	Weight	Specific gravity	Fat	Dry matter	Crude ash	Total nitrogen	Total carbon	Energy value
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Calories*
631	I	5,902.5	1.0332	335.3	900.7	43.4	38.3	483.9	5,378.2
	II	812.8	1.0354	43.3	125.1	7.8	6.8	70.1	784.1
615	I	7,227.2	1.0328	334.6	1,004.6	46.7	44.6	542.4	6,020.0
	II	7,272.8	1.0334	352.7	1,040.7	47.8	47.1	556.7	6,278.7
	III	7,195.0	1.0332	343.2	1,018.8	46.7	46.3	550.8	6,157.0
579	I	8,371.1	1.0330	401.8	1,184.5	53.8	49.2	630.6	7,023.6
	II	8,096.7	1.0331	383.0	1,140.8	51.7	49.4	598.3	6,749.5

TABLE 8.—*Daily production of methane*

Cow No.	Period	Combustible gases		CH_4 computed from combustible gaseous carbon		
		CO_2 by combustion	Carbon equivalent	Total	Per 100 grams digestible carbohydrates	Energy equivalent
		Grams	*Grams*	*Grams*	*Grams*	*Calories*
631	I	540.45	147.38	196.94	5.36	2,627.97
	II	518.77	141.46	189.04	5.23	2,522.55
	III	497.61	135.70	181.32	5.02	2,419.53
615	I	494.50	134.85	180.20	4.84	2,404.59
	II	497.69	135.72	181.36	4.81	2,420.07
	III	505.37	137.82	184.15	4.96	2,457.30
579	I	574.20	156.58	209.23	4.90	2,791.96
	II	583.08	159.00	212.47	5.06	2,835.20

APPARENT DIGESTIBILTIY OF RATIONS BY IMPROVED METHOD

The digestible portion of a feeding stuff is that portion which in passing through the alimentary tract is resorbed, and thereby becomes available for the maintenance of the functions of the organism.

Because of the difficulty of determining true digestibility, however, it has been customary to ascribe to a feed a much higher digestibility than it really has; for, by using the prevailing method of computation which assumes that feed constituents minus feces constituents equal digestible constituents, a part of the feed which is neither resorbable nor useful is included with the digestible. It is a well-known fact that ordinary feeding stuffs for cattle contain ingredients which would be altogether useless for the support of the vital functions of the animal organisms were it not for the presence and activity of microorganisms in the alimentary tract. Although because of such activity, a certain amount of material is converted into substances useful to the body, a considerable part of the original feed substance is changed into forms which can not support the physiological requirements of the animal. It has been customary to consider these useless substances as digestible matter. This gives too high a figure for apparent digestibility. Since the quantity of methane and its equivalent energy can be determined, and since the heat of fermentation of the organisms which liberate the methane can be estimated with a fair degree of accuracy, it is possible to exclude these factors from considerations of apparent digestibility, thus arriving at a closer approximation of true digestibility.

In Table 5 only the visible portions of the excreta have been considered. However, the excreted useless portion of the feed contains gases as well as solids. It is therefore consistent to include the useless gases with the feces and compute the digestibility as has been suggested (Fries) (*3*) by using the following values: Methane, equivalent to 13,344 calories per gram; ratio of methane to carbon dioxid in the products of fermentation in the alimentary tract, 1 to 3.2 by volume; and heat of fermentation equal to 2,000 calories per gram of carbon dioxide produced. The apparent digestibility thus computed will approach the metabolizable and the net values, and hence will be a more accurate expression of nutritive value than will a figure derived, as usual, by a method which fails to consider the important factor of gaseous losses.

Since in the work reported methane is quantitatively determined, whereas the values for carbon dioxide and heat of fermentation are estimated, the digestibility of the rations in this experiment has been computed, (1) on the usual basis of feed constituents minus feces constituents, (2) by considering methane as indigestible, and (3) by taking account also of loss of feed energy through the heat of fermentation. The digestion coefficients as computed by the three methods can be compared by reference to Table 9.

In the preparation of Table 9 the factors used and the method of computation were as follows:

1 liter of methane—0.7168 grams.
1 liter of carbon dioxide—1.9652 grams.
Ratio of methane to carbon dioxide (in fermentation gases) 1: 3.2.
Scheme of computation:
Grams methane ------ liters methane ------ liters of carbon dioxide equivalent to the carbon dioxide of fermentation, or grams methane × 17,546—calories due to fermentation ---------- grams carbon dioxide ------ energy equivalent (calories).

TABLE 9.—*Apparent digestibility of dry matter in terms of energy, computed by three different methods*

Cow No.	Period	Coefficients computed by three methods: 1 Feed minus feces	2 CH_4 added to feces	3 CH_4 and heat of fermentation added to feces	Dry matter digested per day as energy—: Method 1	Method 3	Estimated heat of fermentation
		Per cent	*Per cent*	*Per cent*	*Calories*	*Calories*	*Calories*
631	I	66.67	58.57	47.92	21,642.0	15,558.4	3,455.6
	II	65.93	58.14	47.89	21,338.0	15,498.6	3,316.9
	III	66.75	59.24	49.35	21,488.7	15,887.6	3,181.5
615	I	65.99	58.81	49.38	22,114.0	16,547.6	3,161.8
	II	66.84	59.60	50.07	22,331.0	16,728.9	3,182.2
	III	66.62	59.25	49.56	22,207.0	16,519.6	3,231.1
579	I	68.83	61.23	51.25	25,303.6	18,840.5	3,671.2
	II	68.32	60.61	50.48	25,135.9	18,572.7	3,728.0

In Table 9 are found side by side two columns (the sixth and seventh from the left) giving the dry matter digested per day expressed in terms of energy and computed according to the old and new methods, also one column giving the daily estimated heat of fermentation for each period. Comparing methods 1 and 3 the digestible dry matter, as energy, is from 16.61 to 18.75 per cent less when the nonusable energy of methane and of heat of fermentation is classed with that left in the feces.

THE RESPIRATORY GASES

The respiratory products and gases from all sources are mixed in the outcoming air. The methane as determined comes presumably from a single source; but the carbon dioxide comes from various sources and can not be separated according to origin, the total carbon dioxide therefore representing the metabolism of the cow, of the bacteria of her alimentary tract, and of the man engaged in milking.

CORRECTION FOR MILKER

In respiration-calorimeter experiments with milking cows it is necessary that a man enter the apparatus to do the milking; hence a correction must be applied to the heat emission, and to the water and carbon dioxide as measured. A determination made at the

institute of the carbon dioxide given off by the man engaged in milking in the calorimeter gave 1.0275 grams carbon dioxide per minute for a man weighing 66 kilograms. This amount of CO_2 indicates that the milking of a cow by an experienced milker can be classed as light work in so far as represented by the output of energy and carbon dioxide. The corrections for the milker which have been used are 0.04327 Calorie, 0.01557 gram CO_2, and 0.02231 gram H_2O per minute per kilogram of body weight. These values were obtained from the average figures recorded by Atwater and Benedict (*4*) for two men doing work usually for eight hours per day, described as "more or less severe," and as "reasonable and not at all excessive" by reducing their values to correspond to the carbon dioxide found by an actual determination for the man while milking. Twice it was necessary during the calorimeter experiments for a man to enter the calorimeter chamber for a period of less than a minute. This time has been added to the milker's time and the same correction applied. The total carbon leaving the animal as carbon dioxide is given in Table 10.

THE NITROGEN AND CARBON BALANCE

In order to determine the metabolizable energy it is necessary to correct the urine for gain or loss of nitrogen in the body, hence the need of computing the nitrogen balance. Further, in order to compute the percentage recovery of the feed matter and energy in the milk, the gain or loss of body protein and fat must first be determined. This is made possible by having the income and outgo of nitrogen and carbon balanced. From the nitrogen and carbon balances the corresponding gain or loss of protein, fat, and energy are computed. The results of such a balance of nitrogen and carbon are found in Table 11. The data for the income and outgo of dry matter and the balance of water per day and per head will be found in Tables IV to VI of the appendix.

METABOLIZABLE ENERGY

According to the writers' definition of metabolism—the total of the chemical changes which the constituents of the resorbed feed undergo in the course of their utilization and their conversion into excretory products—metabolizable matter and energy could, generally speaking, represent not only the feed but also such tissues of the body as may be katabolized. However, in connection with studies dealing with the principles underlying animal feeding, it is necessary to use the term metabolizable in a more restricted sense.

TABLE 10.—*Total carbon dioxide*[1] *leaving the animal*

Cow No.	Period	As measured		Man milking			Corrected carbon
		Total CO_2[2]	Carbon as CO_2	CO_2	Carbon	Energy	
		Grams	*Grams*	*Grams*	*Grams*	*Calories*	*Grams*
631	I	5,169.81	1,409.80	13.8	3.87	39.50	1,405.93
	II	5,529.05	1,507.77	11.1	3.11	31.70	1,504.66
	III	5,828.38	1,589.40				1,589.40
615	I	5,165.51	1,408.63	18.9	5.29	53.97	1,403.34
	II	5,353.07	1,459.78	20.5	5.74	58.54	1,454.04
	III	5,469.35	1,491.49	21.9	6.14	62.55	1,485.35
579	I	5,951.13	1,622.87	19.3	5.41	55.12	1,617.46
	II	5,857.07	1,597.22	22.7	6.36	64.82	1,590.86

[1] Corrected for carbon dioxide outgo of man entering the colorimeter to milk the cow
[2] Factor C in CO_2, 0.2727.

TABLE 11.—*Income and outgo of nitrogen and carbon per day and per head*

	Cow 631, period I				Cow 631, period II				Cow 631, period III			
	Nitrogen		Carbon		Nitrogen		Carbon		Nitrogen		Carbon	
	Income	Outgo	Income	Outgo	Income	Outgo	Income	Outgo	Income	Outgo	Income	Outgo
	Gms.	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*
Alfalfa hay	85.4		1,335.0		84.9		1,346.7		89.3		1,355.8	
Composite grain	105.8		1,979.7		105.2		1,956.0		104.8		1,940.9	
Refused feed										0.6		10.2
Feces		49.6		1,087.4		55.7		1,109.9		54.6		1,079.8
Urine		105.4		163.6		132.3		177.3		118.0		154.6
Brushings		1.9		10.3		1.3		7.3		1.6		8.8
Milk		38.3		483.9		6.8		70.1				
Milker			3.9				3.1					
Methane				147.4				141.5				135.7
Carbon dioxide				1,409.8				1,507.8				1,589.4
Difference	4.0			16.2	6.0			291.9		19.3		318.2
	195.2	195.2	3,318.6	3,318.6	196.1	196.1	3,305.8	3,305.8	194.1	194.1	3,296.7	3,296.7

	Cow 615, period I				Cow 615, period II				Cow 615, period III			
	Nitrogen		Carbon		Nitrogen		Carbon		Nitrogen		Carbon	
	Income	Outgo	Income	Outgo	Income	Outgo	Income	Outgo	Income	Outgo	Income	Outgo
	Gms.	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*
Alfalfa hay	87.6		1,369.2		87.1		1,381.2		91.6		1,390.6	
Composite grain	109.6		2,052.4		109.1		2,027.8		108.7		2,012.3	
Feces		52.2		1,150.5		52.0		1,120.3		59.7		1,125.1
Urine		95.0		138.8		96.5		146.5		99.7		150.6
Brushings		2.0		10.0		1.8		9.1		1.7		8.3
Milk		44.6		542.4		47.1		556.7		46.3		550.8
Milker			5.3				5.7				6.1	
Methane				134.9				135.7				137.8
Carbon dioxide				1,408.6				1,459.8				1,491.5
Difference		3.4		41.7	1.2		13.4		7.1		55.1	
	197.2	197.2	3,426.9	3,426.9	197.4	197.4	3,428.1	3,428.1	207.4	207.4	3,464.1	3,464.1

	Cow 579, period I				Cow 579, period II			
	Nitrogen		Carbon		Nitrogen		Carbon	
	Income	Outgo	Income	Outgo	Income	Outgo	Income	Outgo
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Alfalfa hay	96.5		1,531.5		101.6		1,541.8	
Composite grain	119.4		2,220.1		119.6		2,214.4	
Feces		54.0		1,154.0		56.3		1,180.7
Urine		101.9		151.6		112.1		163.2
Brushings		1.3		6.6		1.6		8.2
Milk		49.2		630.6		49.4		598.3
Milker			5.4				6.3	
Methane				156.6				159.0
Carbon dioxide				1,622.9				1,597.2
Difference		9.5		34.7		1.8		55.9
	215.9	215.9	3,757.0	3,757.0	221.2	221.2	3,762.5	3,762.5

The sum of the daily excretions represents a definite amount of energy, and this energy in the last analysis represents feed energy. Hence it is the difference between the gross energy of the feed and

of the corresponding excretions which alone can be of use to the animal.

In other words this difference is the portion of the feed energy which can become useful for maintenance (in the more inclusive sense) work, growth, or other constructive metabolism. It is to this difference that the term "metabolizable energy" has been given. In the literature this portion of the feed has been variously designated, as available energy (as distinguishable from net available energy), fuel value, physiological heat value, etc. From what has been said it must not be inferred that all this difference, or metabolizable energy of the feed, can be utilized for maintenance (in the narrower sense) or production; rather, it is understood that some of this energy must be utilized in the work of digesting the feed, and forming and eliminating the excreta.

Table II shows a somewhat unusual case of a loss of nitrogen accompanied by a gain of carbon (cow 631, periods I and II). In all the other experimental periods nitrogen and carbon were either gained or lost together. This is discussed more fully under gain or loss of body protein and fat.

The end products of protein destruction in the body contain chemical energy, and in order to eliminate the nitrogen factor in the computation of metabolizable energy the animal body is computed to nitrogen equilibrium by the application of a correction for the gain or loss of body nitrogen. The factor used for this correction is that proposed by Rubner and referred to by Armsby (*5*); namely 7.45 Calories per gram of nitrogen. This energy is added in the case of gain, and subtracted in the case of nitrogen loss. Thus, a considerable part of the gross energy of the feed protein can not be utilized by the organism. This correction of the energy for the daily gain or loss of body nitrogen is found in Table 12:

TABLE 12.—*Correction for gain or loss of body nitrogen*

Cow No.	Period	Nitrogen gain	Correction	Cow No.	Period	Nitrogen gain	Correction	Cow No.	Period	Nitrogen gain	Correction
		Grams	*Calories*			*Grams*	*Calories*			*Grams*	*Calories*
631	I	−4.0	−29.8	615	I	+3.4	+25.3	579	I	+9.5	+70.8
	II	−6.0	−44.7		II	−1.2	−8.9		II	+1.8	+13.4
	III	+19.3	+143.8		III	−7.1	−52.9				

GAIN OR LOSS OF BODY PROTEIN AND FAT

Since the glycogen supply of the body does not fluctuate materially under normal conditions of feeding, changes in the nitrogen and carbon of the body may be ascribed to changes in the protein and fat content without appreciable error. From the nitrogen and carbon balances it is therefore possible to compute the gain or loss of body protein and fat. Whether nitrogen is gained or lost it is considered to be accompanied by such an amount of carbon as is contained in an equivalent amount of protein. Thus the gain or loss in fat can be computed from the carbon balance only after the carbon content of the gain or loss of protein has been set aside. From this it follows that in case there is a utilization of a part of the nonnitrogenous fraction of katabolizing tissue protein the amount so utilized is not accounted for and constitutes an error in the compu-

tation. The gain or loss of body protein and fat, computed from the nitrogen and carbon balances, and their equivalents in energy are given in Table 13.

TABLE 13.—*Daily gain (+) or loss (−) of body protein, fat, and energy*

Cow No.	Period	Protein	Fat	Energy		
				Protein	Fat	Sum
		Grams	*Grams*	*Calories*	*Calories*	*Calories*
631	I	−24.0	+37.7	−136.8	+358.2	+221.4
	II	−36.0	+407.2	−205.2	+3,868.4	+3,663.2
	III	+115.8	+337.2	+660.1	+3,203.4	+3,863.5
615	I	+20.4	+40.6	+116.3	+385.7	+502.0
	II	−7.2	−12.6	−41.0	−119.7	−160.7
	III	−42.6	−42.9	−242.8	−407.5	−650.3
579	I	+57.0	+6.3	+324.9	+59.8	+384.7
	II	+10.8	+65.8	+61.6	+625.1	+686.7

The factors used in the computation of the nitrogen and carbon balances, as found in Table 11, to the corresponding amounts of protein, fat, and energy, recorded in Table 12, are the following: Grams of nitrogen multiplied by 6 equals body protein. The average per cent of carbon accepted for protein is 52.54 per cent; hence the number of grams of protein was multiplied by 0.5254 to get the number of grams of carbon in the protein. To compute carbon to fat the number of grams of carbon was multiplied by the factor 1.31, which corresponds practically to an average of 76.5 per cent of carbon in animal fat. The energy equivalents for protein and fat were considered to be 5.7 and 9.5 Calories per gram, respectively.

COMPUTATION OF METABOLIZABLE ENERGY

The milk of the cow may be considered in the same light as body gain, in which case the energy of the excreta must be corrected for the potential energy of the milk protein. On the other hand it may be considered as a product in a sense apart from the body which, being neither body gain nor an excretum, is not involved in the computation of metabolizable energy. Although a column setting forth the metabolizable energy according to the first view, that is, considering the milk as body gain, is given, considering it as a product entirely apart from body gain is assumed to be the correct view for this class of experiments.

In Table 14 are found the results obtained by using the following three methods of computation:

No. 1. Gross energy of the feed minus the chemical energy of feces, urine, brushings, and methane, the nitrogenous outgo being corrected to body nitrogen equilibrium, ignoring the milk.

No. 2. The same as No. 1 except that the heat of fermentation is treated as an excretum.

No. 3. The same as No. 2 except that the milk is treated as body gain.

In Table 14 the values for the gross energy of the feed and of the feces are obtained from the digestibility tables in the appendix. The other values needed in the computation are recorded in preceding tables. A comparison of the metabolizable energy as determined by the three methods of computation shows the amount metabolizable according to method 2 to be from 17.28 to 19.92 per

cent less than according to method 1, and that the amount by method 3 is reduced by about 2 per cent additional. Reckoned as per cent of the digestible, however, the metabolizable energy, according to methods 2 and 3, will show higher figures than by method 1.

TABLE 14 (Part 1).—*Data incident to computation of metabolizable energy*

Cow No.	Period	Chemical energy: Feces	Chemical energy: Urine	Chemical energy: Brushings	Chemical energy: Methane	Chemical energy: Heat of fermentation	Corrections to excretory energy for protein: Body gain or loss	Corrections to excretory energy for protein: Milk
		Calories	*Calories*	*Calories*	*Calories*	*Calories*	*Calories*	*Calories*
631	I	10, 820. 6	1, 583. 8	110. 1	2, 628. 0	3, 455. 6	−29. 8	+285. 0
	II	11, 026. 0	1, 691. 1	78. 3	2, 522. 5	3, 316. 9	−44. 7	+50. 7
	III	10, 702. 9	1, 431. 8	93. 7	2, 419. 5	3, 181. 5	+143. 8	(Dry)
615	I	11, 397. 3	1, 323. 4	107. 5	2, 404. 6	3. 161. 8	+25. 3	+331. 9
	II	11, 076. 7	1, 400. 3	87. 6	2, 420. 1	3, 182. 2	−8. 9	+360. 1
	III	11, 125. 3	1, 406. 3	89. 1	2, 457. 3	3, 231. 1	−52. 9	+344. 6
579	I	11, 459. 0	1, 487. 2	70. 2	2, 792. 0	3, 671. 2	+70. 8	+366. 5
	II	11, 655. 5	1, 611. 3	87. 7	2, 835. 2	3, 728. 0	+13. 4	+367. 9

Cow No.	Period	Gross energy of feed	Energy of excreta (corrected): Method 1	Energy of excreta (corrected): Method 2	Energy of excreta (corrected): Method 3	Metabolizable energy: Method 1	Metabolizable energy: Method 2	Metabolizable energy: Method 3
		Calories	*Calories*	*Calories*	*Calories*	*Calories*	*Calories*	*Calories*
631	I	32, 462. 6	15, 112. 7	18, 568. 3	18, 853. 3	17, 349. 9	13, 894. 3	13, 609. 3
	II	32, 364. 0	15, 273. 2	18, 590. 1	18, 640. 8	17, 090. 8	13, 773. 9	13, 723. 2
	III	32, 191. 6	14, 791. 7	17, 973. 2	17, 973. 2	17, 399. 9	14, 218. 4	14, 218. 4
615	I	33, 511. 3	15, 258. 1	18, 420. 2	18, 752. 1	18, 253. 2	15, 091. 1	14, 759. 2
	II	33, 407. 8	14, 975. 7	18, 138. 0	18, 517. 1	18, 432. 1	15, 269. 8	14, 890. 7
	III	33, 332. 3	15, 025. 1	18, 256. 2	18, 601. 8	18, 307. 2	15, 076. 1	14, 730. 5
579	I	36, 762. 6	15, 879. 2	19, 550. 4	19, 916. 9	20, 883. 4	17, 212. 2	16, 845. 7
	II	36, 791. 4	16, 203. 1	19, 931. 1	20, 299. 0	20, 588. 3	16, 860. 3	16, 492. 4

TABLE 15.—*Comparison of two methods of computation of metabolizable energy*

Cow No.	Period	Usual method: Total energy: Digestible	Usual method: Total energy: Metabolizable	Usual method: Digestible energy metabolizable [1]	Improved method: Total energy: Digestible [2]	Improved method: Total energy: Metabolizable [3]	Improved method: Digestible energy metabolizable [4]
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
631	I	66. 67	53. 44	80. 16	47. 92	42. 80	89. 31
	II	65. 93	52. 81	80. 10	47. 89	42. 56	88. 87
	III	66. 75	54. 05	80. 97	49. 35	44. 17	89. 50
Average		66. 45	53. 43	80. 41	48. 39	43. 18	89. 23
615	I	65. 99	54. 47	82. 54	49. 38	45. 03	91. 19
	II	66. 84	55. 15	82. 51	50. 07	45. 62	91. 11
	III	66. 62	54. 92	82. 44	49. 56	45. 23	91. 26
Average		66. 48	54. 85	82. 50	49. 67	45. 29	91. 19
579	I	68. 83	56. 80	82. 52	51. 25	46. 82	91. 36
	II	68. 32	55. 96	81. 91	50. 48	45. 83	90. 79
Average		68. 58	56. 38	82. 22	50. 86	46. 33	91. 08

[1] From "Metabolizable energy," method 1, Table 14, and "Digested Calories," method 1, Table 9.
[2] From Table 9, method 3.
[3] From "Metabolizable energy," method 2, Table 14, and "Gross energy of feed," Table 14.
[4] From "Metabolizable energy," method 2. Table 14, and "Digested Calories," method 3, Table 9.

Since the energy of the digestible nutrients is determined by subtracting from the gross energy of the feed the energy of the unused residue from the same, then all factors whatsoever of unused residuum should be consistently accounted for in this computation and that of metabolizable energy as well; and, in view of the fact that this is a departure from the customary usage, the usual method—based upon feed constituents minus feces constituents—as well as the improved method—considering also other excreta—has been used. That the heat of fermentation does not belong either to the digestible or to the metabolizable portion seems clear, the only question being as to the accuracy of the basis for its estimation.

The metabolizable energy computed as per cent of the digestible (method 1, compare with the usual, and method 2 with the improved conception of digestibility) are reported in Table 15. This table shows a close agreement from period to period, and also among the different animals.

HEAT EMISSION

The heat given off by the animal while in the respiration calorimeter is removed from the apparatus in a current of water, in water vapor, in excreta, and in milk, and the sum of the heat thus removed corrected for the introduction of feed and water as well as for the man engaged in milking, is the total heat emission. Under the heading "radiation," etc., in Table 16 is included all the heat except that removed as latent heat of water vapor, and in the last column the heat by radiation is expressed in per cent of the total. This heat emission, however, is not necessarily identical with the total heat production of the ration fed, but must be corrected for change in live weight of the animal and for any change in the body temperature. This correction has the effect of rendering the data representative of the body in such condition as at the beginning of the experiment.

TABLE 16.—*Heat emission per day and animal*

Cow No.	Period	Radiation and conduction	Latent heat of water vapor	Total heat	By radiation, etc., in per cent of total
		Calories	*Calories*	*Calories*	*Per cent*
631	I	7,359.6	4,487.6	11,847.2	62.12
	II	7,750.2	4,451.6	12,201.8	63.52
	III	9,265.4	4,164.7	13,430.1	68.99
615	I	7,843.3	3,870.8	11,714.1	66.96
	II	8,619.2	3,577.9	12,197.1	70.66
	III	8,871.8	3,519.2	12,391.0	71.60
579	I	9,450.8	4,204.5	13,655.3	69.21
	II	9,386.5	3,861.7	13,248.2	70.85

INFLUENCE OF BODY TEMPERATURE

The temperature of the body of the animals was taken daily at the rectum, by means of the usual clinical thermometer. During the feeding in the barn this temperature was always taken at the same hour, but during the calorimeter experiment could not be taken at the same hour of the day as at the end without destroying the equilibrium of the apparatus. Also at this time it had not been learned that the thermometer must be inserted to a depth of at least 6 inches in order to obtain correct readings, as Kriss (*6*) has subse-

quently shown to be necessary. Further, the writers are not sure that the rather sudden temperature changes recorded indicate correctly the temperature changes of the whole body. In view of these uncertainties the small variations, a few tenths of 1 degree Fahrenheit, while in the calorimeter are of doubtful significance; and, therefore, in this experiment no corrections have been made for these apparent changes in body temperature.

CHANGES IN LIVE WEIGHT DURING THE CALORIMETER EXPERIMENT

Between the time of entering and leaving the respiration calorimeter there is frequently a considerable change in the live weight of the animal. This change is due especially to variation in the amount of water consumed; also, to an important extent, to irregularity in the voiding of excreta; and, further, to actual gain or loss of body substance.

TABLE 17.—*Changes in live weight of the cow while in the calorimeter*

	Period I		Period II		Period III	
	Gain	Loss	Gain	Loss	Gain	Loss
Cow 631:	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Water		18, 894. 2	5, 585. 7			10, 536. 2
Dry matter irregularity—						
Milk		66. 0		52. 3		
Excreta	578. 6		1, 332. 5		614. 1	
Protein		24. 0		36. 0	115. 8	
Fat	37. 7		407. 2		337. 2	
Balance	18, 367. 9			7, 237. 1	9, 469. 1	
	18, 984. 2	18, 984. 2	7, 325. 4	7, 325. 4	10, 536. 2	10, 536. 2
Cow 615:						
Water		13, 851. 8		3, 250. 5		17, 546. 5
Dry matter irregularity—						
Milk		3. 5		44. 5		31. 7
Excreta	874. 3		941. 0		617. 8	
Protein	20. 4			7. 2		42. 6
Fat	40. 6			12. 6		42. 9
Balance	12, 920. 0		2, 373. 8		17, 045. 9	
	13, 855. 3	13, 855. 3	3, 314. 8	3, 314. 8	17, 663. 7	17, 663. 7
Cow 579:						
Water		20, 772. 9		17, 086. 4		
Dry matter irregularity—						
Milk	8. 0		26. 5			
Excreta	740. 0		641. 6			
Protein	57. 0		10. 8			
Fat	6. 3		65. 8			
Balance	19, 961. 6		16, 341. 7			
	20, 772. 9	20, 772. 9	17, 086. 4	17, 086. 4		

As already explained, during the calorimeter period the animal is assumed to have the same body temperature at the beginning and at the end of the experiment, so that no correction was made for change of temperature; but a heat correction is necessary for the change in live weight. Hence the character and quantity of this change must be determined, and a balance of the live weight of the animal has therefore been computed, which shows the total daily change in live weight due to various irregularities of excretion, etc., and the gain or loss of body tissue while the animal was in the calorimeter. The various items which enter into such a computation and the balances are given in Table 17. For the daily gain or loss of body protein and fat, the average figures as determined for the whole experimental period have been used, but the water is the

actual water balance from the calorimeter period. The dry matter representing irregularity in the excreta and production of milk is the difference between the daily average for the experimental period and the amount produced during the calorimeter period.

The daily balances for the different periods and animals show a great variation, ranging from +7.2 kilograms to −19.1 kilograms change in live weight. This clearly demonstrates the unreliability of live weight as a measure in exact experiments, and the necessity, in work in which live weights must be used, of basing conclusions on an average of several successive daily weights. A single weighing may happen to be correct, but, on the other hand, according to the above figures, it may be decidedly wrong, especially when intended to measure the gain or loss of body tissue.

HEAT PRODUCTION

To correct the heat emission for the change in live weight, in computing the heat production at a constant weight, the following factors for specific heat have been used: Water equals 1, dry matter equals 0.4, body protein and fat equals 0.3 and 0.66, respectively, the last two being estimated values as used by Armsby and Fries. The heat correction for the body gain or loss in live weight as thus computed is found in Table 18, which also gives the daily heat production.

The corrections for change in live weight are considerable, ranging as they do from +132.1 to −419.7 Calories.

COMPUTED HEAT PRODUCTION

For various reasons it is desirable to compute the heat production of an animal (indirect calorimetry) from the results of the gas and dry-matter analyses. Making this computation for a milking cow, under varying conditions, is a new problem and one which requires discussion.

TABLE 18.—*Correction for change in live weight, and daily heat production*

Cow No.	Period	Body loss (−) or gain (+)			Irregular excretion of dry matter	Temperature difference	Correction	Daily heat	
		Water	Protein	Fat				Emission (corrected)	Production (corrected)
		Grams	*Grams*	*Grams*	*Grams*	°C.	*Calories*	*Calories*	*Calories*
631	I	−18,894.2	−24.0	+37.7	−[1] 66.0 +[2] 578.6	20.53	−383.3	11,847.2	11,463.9
	II	+5,585.7	−36.0	+407.2	−52.3 +1,332.5	20.79	+132.1	12,201.8	12,333.9
	III	−10,536.2	+115.8	+337.2	+614.1	21.02	−210.9	13,430.1	13,219.2
615	I	−13,851.8	+20.4	+40.6	−3.5 +874.3	20.68	−278.6	11,714.1	11,435.5
	II	−3,250.5	−7.2	−12.6	−44.5 +941.0	20.59	−59.8	12,197.1	12,137.3
	III	−17,546.5	−42.6	−42.9	−31.7 +617.8	20.68	−358.8	12,391.0	12,032.2
579	I	−20,772.9	+57.0	+6.3	+8.0 +740.0	20.52	−419.7	13,655.3	13,235.6
	II	−17,086.4	+10.8	+65.8	+26.5 +641.6	20.99	−352.0	13,248.2	12,896.2

[1] Milk. [2] Excreta.

A milking cow may be maintaining her body tissue; she may lose or gain both body protein and fat, or she may lose one and gain the other. These different conditions of body loss or gain require appropriately differing consideration.

Thus, for example, starting with the assumption that the energy of the feed minus the energy of the excreta equals the metabolizable energy then with an animal in nutritive equilibrium the total heat production (Table 19) equals the metabolizable energy. In case the animal gains body tissue the energy of the excreta is thereby lowered, the metabolizable energy is greater than the total heat production, and in computing the heat production, a correction for the chemical energy of the body gain must be subtracted from the metabolizable. Should the animal lose body tissue, then the heat production and the energy of the excreta are thereby increased by the energy equivalent of the tissue lost, and in computing the heat production the chemical energy of the body loss must be added to the metabolizable.

It may be assumed that in the case of a cow receiving sufficient energy in her feed for maintenance, and also to supply the greater portion of the energy of the milk, any loss of body tissue goes to support the milk production, and that therefore the energy of this loss has been transferred to the milk. This transformation of body tissue into milk involves but a small loss of energy. Since the amount of this loss is not known to the writers, it has been omitted in the computation. Desiring at this time only to compare the total heat production as measured with the computed heat production, the heat of fermentation has also been ignored.

The computed heat production per day and head has been calculated in accordance with the foregoing methods and the results given in Table 19.

TABLE 19.—*Computed heat production* (*indirect calorimetry*)

	Period I		Period II		Period III	
	Intake	Outgo	Intake	Outgo	Intake	Outgo
	Calories	*Calories*	*Calories*	*Calories*	*Calories*	*Calories*
Cow 631:						
Feed	32, 462. 6		32, 364. 0		32, 191. 6	
Feces		10, 820. 6		11, 026. 0		10, 702. 9
Urine (uncorrected)		1, 583. 8		1, 691. 1		1, 431. 7
Methane		2, 628. 0		2, 522. 5		2, 419. 5
Brushings		110. 1		78. 3		93. 7
Milk		5, 378. 2		784. 1		
Body protein	136. 8		205. 2			660. 1
Body fat		358. 2		3, 868. 4		3, 203. 4
Balance		11, 720. 5		12, 598. 8		13, 680. 3
Total	32, 599. 4	32, 599. 4	32, 569. 2	32, 569. 2	32, 191. 6	32, 191. 6
Cow 615:						
Feed	33, 511. 3		33, 407. 8		33, 332. 3	
Feces		11, 397. 3		11, 076. 7		11, 125. 3
Urine (uncorrected)		1, 323. 4		1, 409. 2		1, 406. 3
Methane		2, 404. 6		2, 420. 1		2, 457. 3
Brushings		107. 5		97. 6		89. 1
Milk		6, 020. 0		6, 278. 7		6, 157. 0
Body protein		116. 3	41. 0		242. 8	
Body fat		385. 7	119. 7		407. 5	
Balance		11, 756. 5		12, 286. 2		12, 747. 6
Total	33, 511. 3	33, 511. 3	33, 568. 5	33, 568. 5	33, 982. 6	33, 982. 6
Cow 579:						
Feed	36, 762. 6		36, 791. 4			
Feces		11, 459. 0		11, 655. 5		
Urine (uncorrected)		1, 487. 2		1, 611. 3		
Methane		2, 792. 0		2, 835. 2		
Brushings		70. 2		87. 7		
Milk		7, 023. 6		6, 749. 5		
Body protein		324. 9		61. 6		
Body fat		59. 8		625. 1		
Balance		13, 545. 9		13, 165. 5		
Total	36, 762. 6	36, 762. 6	36, 791. 4	36, 791. 4		

The heat production as computed and as measured by the respiration calorimeter is arranged for comparison in Table 20. The computed is also expressed in per cent of the observed.

THE OBSERVED AND COMPUTED HEAT PRODUCTION

The fairly close agreement between the computed and the observed heat production may be taken as a measure of the degree of accuracy to be expected from experiments on milk cows in a respiration chamber, using a bomb calorimeter for determining the energy of feed and excreta.

In period III, cow 631, the heat measurement was adversely affected by the presence of an excess of air in the absorber water, and hence the heat for certain periods of time could not be measured. From the other main portion of the day the total heat for the 24 hours was computed by applying to the missing smaller sections the average heat per minute, as observed during standing and lying. This, of course, increases the possibility of error. However, the comparison with the computed heat production proves it to have been very small.

It will be noted that the computed heat production is, in seven cases out of eight, not more than 3.5 per cent greater than the observed heat production. In the nature of the case, this difference covers a considerable number and diversity of errors, all presumably slight. It appears that the true value lies above the observed, and that the computed values are therefore less in excess of the actual than is suggested by a statement of the computed as per cent of the observed. In the opinion of the writers the determination of heat production by indirect calorimetry is sufficiently accurate for purposes of research in the feeding of farm animals.

TABLE 20.—*Observed and computed heat production*

Cow No.	Period	Heat production		Computed in per cent of observed
		Observed	Computed	
		Calories	*Calories*	*Per cent*
631	I	11,463.9	11,720.5	102.24
	II	12,333.9	12,598.8	102.15
	III	13,219.2	13,680.3	103.49
615	I	11,435.5	11,756.5	102.80
	II	12,137.3	12,286.2	101.23
	III	12,032.2	12,747.6	105.95
579	I	13,235.6	13,545.9	102.34
	II	12,896.2	13,165.5	102.09

NET ENERGY OF FEED FOR BODY GAIN AND MILK PRODUCTION

Before taking up the question of standing and lying it is desirable to determine the percentage utilization of the available metabolizable energy for body gain and also for milk production, using the computed heat values.[3] Cow 631 offers an excellent opportunity for such a comparative study. She was in full milk during one period, was almost dry in the second, and fully dry in the third period, whereas the ration remained the same throughout all the periods. This animal was standing during less time than she was lying, but the

[3] In the following computations the data for the observed heat production have not been used, but are reserved pending the solution of a problem as to method of use.

ratio of time standing to time lying was about the same during each of the three periods.

THE MAINTENANCE REQUIREMENT

On account of unavoidable circumstances, it was impossible to determine the maintenance requirements of the experimental subjects. It was necessary, therefore, to assume these requirements on the basis of published averages. Lately Hills (7), from his extensive long-time practical maintenance experiments, reached the conclusion that Armsby's and Eckles's standards for maintenance of cattle per 1,000 pounds live weight are essentially correct. The maintenance requirements of the three cows therefore have been computed according to Armsby's standard; they are based upon the live weight of each period for cow 631, and on the average live weight for cows 615 and 579. The results thus computed expressed in weight of dry matter of the feed, and its equivalent in metabolizable energy computed according to both the usual and improved methods, are given in Table 21.

TABLE 21.—*Computed maintenance requirements of the subjects of the experiment reported*

Cow No.	Period	Average live weight	Digestible true protein	Net energy	Feed dry matter		Metabolizable energy	
					Grain mixture	Alfalfa hay	Usual method	Improved method
		Kilograms	*Grams*	*Therms*	*Grams*	*Grams*	*Calories*	*Calories*
631	I	334	185	4.88	2,132	1,445	8,609.9	6,895.1
	II	360	195	5.13	2,236	1,523	8,935.2	7,201.1
	III	390	205	5.40	2,364	1,600	9,644.3	7,880.9
615	I	366	196	5.17	2,259	1,532	9,299.5	7,688.6
	II		196	5.17	2,259	1,532	9,410.5	7,785.1
	III		196	5.17	2,259	1,532	9,373.5	7,719.1
579	I	370	198	5.22	2,282	1,545	9,785.8	8,065.5
	II		198	5.22	2,282	1,545	9,524.8	7,800.1

In order that the continuity of the computations may be maintained Table 22 has been inserted to show the influence of the correction for body gain or loss on the availability of the metabolizable energy for milk production.

TABLE 22.—*Influence of correction for gain or loss by the body on availability of the metabolizable energy for milk production*

Cow No.	Period	Energy correction for body gain		Energy available for milk production	
		Usual method	Improved method	Usual method	Improved method
		Calories	*Calories*	*Calories*	*Calories*
631	I	+444.4	+363.2	8,295.6	6,636.0
	II	+7,353.6	+6,009.1	802.0	563.7
	III				
615	I	+1,007.7	+823.5	7,946.0	6,579.3
	II	−160.7	−160.7	9,173.3	7,616.5
	III	−650.3	−650.3	9,584.0	8,007.3
579	I	+772.3	+631.1	10,325.3	8,515.6
	II	+1,378.5	+1,126.5	9,685.0	7,933.7

METABOLIZABLE ENERGY AVAILABLE FOR PRODUCTION

If the metabolizable energy of the feed required for maintenance is subtracted from the total metabolizable energy in the feed, the amount available for production is obtained. These values as well as those of the actual milk production and the body gain in calories are recorded in Table 23.

Having the above data the computation of the percentage utilization and the net energy of the feed for the different types of production can be made.

TABLE 23.—*Metabolizable energy available for milk production and body gain*

Cow No.	Period	Available for production		Actual production	
		Usual method	Improved method	Milk	Body gain
		Calories	*Calories*	*Calories*	*Calories*
631	I	8,740.0	6,999.2	5,378.2	+221.4
	II	8,155.6	6,572.8	784.1	+3,663.2
	III	7,755.7	6,337.6		+3,863.5
615	I	8,953.7	7,402.8	6,020.0	+502.0
	II	9,012.6	7,455.8	6,278.7	−160.7
	III	8,933.7	7,357.0	6,157.0	−650.3
579	I	11,097.6	9,146.7	7,023.6	+384.7
	II	11,063.5	9,060.2	6,749.5	+686.7

NET ENERGY FOR BODY INCREASE

In period III cow 631 was dry, and gained body substance equivalent to 3,863.5 Calories. If this amount of gain is divided by the amount of available metabolizable energy, according to the two methods of computing it, the following results are obtained:

$$\frac{3{,}863.5 \times 100}{7{,}755.7} = 49.815 \text{ per cent utilization (usual method).}$$

$$\frac{3{,}863.5 \times 100}{6{,}337.6} = 60.961 \text{ per cent utilization (improved method).}$$

Since the body gain expressed in calories (assuming that there is no milk production) represents the net energy of the difference between the total feed eaten and the amount needed for maintenance, the net energy for body production per kilogram dry matter of feed mixture is obtained by dividing the calories of body gain by the difference between gross intake of feed and the maintenance requirement.

Thus: 7,151.0−3,963.6=3,187.4 grams of feed mixture; and 3,863.5 Calories (body gain)÷3.1874 kilograms (gross intake minus the maintenance requirement) =1.2121 Therms net energy per kilogram dry matter of feed for body increase.

NET ENERGY FOR MILK PRODUCTION

Turning now to period I, the milk production of cow 631 was equivalent to 5,378.2 Calories, and at the same time the body gain was equivalent to 221.4 Calories.

The utilization of the metabolizable energy available for production was 49.815 per cent according to the usual method, or 60.961 per cent according to the improved method of computation. Using these percentages a correction for the 221.4 Calories gain by the body is obtained. Therefore, 221.4÷0.4982=444.4 Calories, and 221.4÷0.6096=363.2 Calories, respectively. Deducting these values from

the two sets of metabolizable calories available, the total metabolizable energy available for milk production is obtained.

	8,740.0 usual method.	6,999.2 improved method.
	444.4	363.2
Difference,	8,295.6 Calories.	6,636.0 Calories.

These two values represent the amount of metabolizable energy available for milk production. Dividing the milk yield by these values the following figures are obtained:

$$\frac{5,378.2 \times 100}{8295.6} = 64.832 \text{ per cent utilization (usual method),}$$

or

$$\frac{5,378.2 \times 100}{6636.0} = 81.046 \text{ per cent utilization (improved method).}$$

To obtain the net energy value of the feed for milk production it is necessary first to correct the maintenance requirement so as to include the body gain and then subtract this amount from the total feed eaten. Thus, in period I, cow 631, the maintenance requirement including the body gain will be, using the old method, according to the proportion; maintenance metabolizable: maintenance metabolizable $+ 221.4 \div 49.815$: : weight of maintenance ration : X. X = dry matter of feed.

Thus 8,609.9 : 9054.3 : : 3577 : X. X = 3,761.8 grams of feed.
Total ration 7,208.4 − 3,761.8 = 3,446.6 grams of feed mixture for production of milk.

Dividing the milk calories by this amount the net energy of the feed for milk production per kilogram dry matter of the feed is obtained.

Thus 5378.2 ÷ 3.4466 = 1.5604 therms of net energy for milk production.

For body increase	1.2121	Therms of net energy.
For milk production	1.5604	
Difference	0.3483 = 22.32 per cent.	

In this connection it is of interest to note that Hansson (*8*) from a very large number of long-time practical group experiments with milking cows has obtained for the individual grain barley, which is the standard for the feed-unit system, a net energy value for body increase equal to 1.650 Therms per kilogram of grain containing 14.5 per cent moisture, and for milk production a net energy value of 2.100 Therms, a difference of 21.5 per cent.

This shows a remarkably close agreement for the percentage difference between net energy for body increase and net energy for milk production, as found by different experimenters, especially when the extremely *different methods of experimentation* by means of which the results were obtained are considered.

It must be borne in mind, however, that in these experiments the maintenance requirement was computed from published averages and not determined for the cow referred to above.

Having thus determined the net energy value of the feed for body gain from the dry period of the one cow, by applying this value to the other cows, the percentage utilization of the metabolizable energy available for milk production may be computed in the manner previously described. The results of such computations are recorded in Table 24.

It will be noted in connection with the data presented in Table 24 that in summarizing the results of these experiments the net energy values given for milk production are based upon the results obtained with cow 631.

It is not impossible, therefore, that the proximity of parturition in the latter period contributed a confusing influence in the computation of the net energy value for body increase. Judgment as to this possibility must await further evidence.

Since such a material difference has been found to exist between the two kinds of production values, it is desired for the present to call attention to them by using the terms, "Net energy value of feed for body gain" and "Net energy value of feed for milk production."

TABLE 24.—*Percentage utilization of metabolizable energy available for milk production and the net energy value for milk production*

Cow No.	Period	Utilization for milk production		Net energy for milk	Interval between periods
		Usual method	Improved method		
		Per cent	*Per cent*	*Therms*	*Days*
631	I	64.83	81.05	1.560	56
	II	97.76	139.10	2.322	42
	III	Dry.	Dry.	0.000	
615	I	75.76	91.51	1.776	42
	II	68.44	82.43	1.699	
	III	64.24	76.89	1.589	
579	I	68.02	82.48	1.739	42
	II	69.69	85.08	1.750	

Such distinction is in keeping with what Armsby has said on the subject of milk production, and with the practice of some present-day Scandinavian investigators.

These large differences in the percentage utilization of the available metabolizable energy and the net energy of the feed for milk and for body gain are evidence suggesting that, when an animal has sufficient feed, the dry matter of the feed does not first become body tissue and later milk. It is a process more direct and less expensive.

"DRYING-UP" PERIOD

In the computations to obtain the percentage utilization of the available metabolizable energy the results derived from experiments with the respiration calorimeter were applied, in each case, to the average milk and body gain for the digestion period.

It is not entirely satisfactory to study milk production in a cow which is giving less than 1 kilogram of milk in 24 hours. In period II, cow 631 though giving only 0.8 kilogram of milk per day was treated as in the other milking periods and is included in the above table. This period, however, requires a special consideration and discussion. During the drying-up period, which is represented by the data for cow 631, the percentage of daily decrease in milk production was considerable; and, since the calorimeter work was done at the beginning instead of the middle of the period, it is not a true representation of the average production during this rapid and continuous decrease. If the results obtained with the respiration calorimeter are applied to the milk yield of the same day, and the body gain corrected in proportion to the milk yield and the body gain of

periods I and III, the following recomputation will give utilization and net energy values for this period which are probably more nearly correct.

The milk on the calorimeter day was 1.19 kilogram = 1,147.9 Calories, a difference of 363.8 Calories from the average. This difference in milk production, based on period I, would be $363.8 \div 0.6483 = 561.2$ Calories (usual method) or $363.8 \div 0.8105 = 448.9$ Calories (improved method) of available metabolizable energy.

But these values represent the reduction in body gain which, based on the percentages obtained in period III, would be by the usual method equal to $561.2 \times 0.49815 = 279.6$ Calories of body gain.

In period II the gain was 3,663.2 Calories, and $3{,}663.2 - 279.6 = 3{,}383.6$ Calories corrected gain. Applying the percentage utilization previously computed we have $3{,}383.6 \div 0.49815 = 6{,}792.3$ Calories (usual method), or $3{,}383.6 \div 0.60961 = 5{,}550.4$ Calories (improved method) of available metabolizable energy which, deducted from the total available, leaves for milk production the following:

8, 155. 6	6, 572. 8
6, 792. 3	5, 550. 4
1, 363. 3 Calories.	1, 022. 4 Calories.

The corresponding percentage utilization would then be:

$$\frac{1{,}147.9 \times 100}{1{,}363.3} = 84.20 \text{ per cent utilization (usual method).}$$

$$\frac{1{,}147.9 \times 100}{1{,}022.4} = 112.27 \text{ per cent utilization (improved method).}$$

The net energy for milk production can be computed as follows:

$8{,}935.2 : 8{,}935.2 + 6{,}792.3 : 3.759 : X. \quad X = 6{,}616.4.$

$7{,}190.1 - 6{,}616.4 = 573.7$ grams dry matter and 1,147.9 Calories $\div 0.5737 = 2.000$ Therms net energy per kilogram feed.

All these results suggest that the computed maintenance ration, at least for cow 631, period III, was too low. It had been computed in consideration of the increase in live weight of the animal; but since this increase must have been due largely to the development of the fetus, it seems possible that the increased weight on this account would represent more protoplasmic activity than the same increase of body weight apart from the fetus, the maintenance requirement, therefore, being greater. This may be true not only for period III but also for period II. In the light of other results, and the above hypothesis, it would appear that the maintenance requirement as computed for period III is about 2 per cent too low. If an allowance of 2 per cent increase in maintenance for period III is made, and the new values for body gain determined, the percentage utilization of the available metabolizable energy for milk production, with cow 631, period II, would be, computing as before, 74.91 per cent, or 98.92 per cent utilization (usual and improved methods, respectively), and the net energy for milk production 1.78 Therms per kilogram of dry matter of the ration.

Thus it is seen that a change of 2 per cent in the values for maintenance will make the values applying to cow 631, period II, correspond to the other milking periods. The data as to cow 631, period II, therefore, constitute in reality a fair proof of the accuracy of the experiment as a whole, and also an indication that the maintenance requirement of an animal in the later stage of gestation may

be higher than the average for the same body weight if the animal were not pregnant. If this is the correct interpretation, then the period in question also indicates that the estimated heat of fermentation used in the "improved method" of computing the metabolizable energy is not far from the correct value.

The above observations as to the increased maintenance requirement during pregnancy in the cow are readily understood in the light of the finding by Magnus-Levy (*9*) of a steady increase of oxygen requirement throughout the course of pregnancy in woman, the conclusion of Murlin (*10*) that the extra metabolism of the pregnant female dog, as related to reproduction activity, is proportional to the weight of the puppies at birth, and the findings of Carpenter and Murlin (*11*), in a study of metabolism in three pregnant women, that the difference in heat production per hour, before and after parturition, was very nearly the same as that of the newborn infant, and that the rate of metabolism of the infant was 2.6 times that of the mother, in terms of calories per kilogram of body weight.

EFFECT OF ADVANCE IN LACTATION

Eliminating cow 631, which was studied during only one period in which milk was produced in any considerable quantity, the effect of advance in lactation on utilization of the available energy for milk production with the other two cows can be studied (Table 22).

Cow 615, whose tests extended over a period of 94 days, offers the best opportunity for study. With this cow there was a decrease in the percentage utilization of the available energy for milk production in each period. With cow 579, which had been in milk about three months at the time of the first period, there was a slight increase in percentage utilization during the second period. Hence no definite conclusion can be drawn from this experiment so far as the effect of the advance of lactation on the percentage utilization of the available metabolizable energy for milk production is concerned, and the accumulation of additional data must be awaited.

STANDING AND LYING

The results of nutrition investigations, in order to be comparable, must represent certain uniform experimental conditions, any variations from which must be taken into account in the application of the conclusions. Thus it is customary to compute the experimental results obtained with animals of different weights so as to apply to animals of standard weights, usually either 1,000 pounds or 500 kilograms live weight. Also it is understood that feeding standards apply exactly only under conditions essentially the same as those under which they have been established, which in connection with this study means comfortable stable conditions and from which it follows that allowance should be made in the application of the conclusions and of all feeding standards for any considerable departure from the basic conditions implied.

Earlier experiments on steers with the respiration calorimeter established the fact that irrespective of the kind or quantity of feed eaten there is always a large percentage difference in the amount of heat given off by the animal according to its position in regard to standing and lying. Although the animal in the course of the day in these experiments always gave off more heat per minute while standing than while lying, as the data accumulated it was noticed

that results in different periods with different kinds or quantities of feed did not agree so closely as was to be expected in consideration of the time of standing and lying and the respective rates of heat emission.

This led Armsby to collect the available data and, after a careful study of the relation of change in quantity of feed and of variation in length of time spent standing and lying to increase in heat emission due to standing, to make the following statement (*12*): "It is clear, therefore, that despite the apparent uniformity of experimental conditions the metabolism of the animals was affected by influences other than the feed or the proportion of time spent standing." That is, the total observed difference in heat emission per minute between standing and lying can not be ascribed entirely to the muscular work due to standing.

The following are some of the outstanding experimental facts as to heat emission in relation to standing and lying:

The average heat emission per minute of standing is always much greater than that per minute of lying.

Body temperature does not change with change of position.

With an increasing ration there is usually an increment in the heat emission per 24 hours of standing. There is, however, a lack of uniformity in the results, and negative differences have also been observed.

With an increase in feed there is almost invariably an increase in methane fermentation, and a part of the heat of fermentation will be included in the increment of standing.

An increase of a few kilograms in live weight does not noticeably affect the heat emission during standing.

There is no strict quantitative relation between the heat emission per minute and the length of time spent standing.

Møllgaard (*13*), discussing the results of standing and lying, did not find the consumption of oxygen to vary with the time spent in these positions, and believes that there is in the end a compensation taking place within the animal of such nature that after a longer period of standing, and therefore greater fatigue, the metabolism of the animal decreases on lying down to a greater extent than after a shorter period of standing. However, experiments of the writers cover many instances in which long periods of standing do not influence the heat emission during lying to a greater extent than do shorter periods; and Møllgaard's hypothesis does not explain the irregularities in the oxygen consumption, or the processes involved in producing such differences in heat emission as have been noticed in the calorimeter experiments.

Observations on the heat emission during lying and standing, together with the fact that at certain periods of the day the oxygen consumption [4] of the animal does not follow the carbon-dioxide production, would seem to indicate that conclusions can not be based on short sections of the experimental day since these are not reliably typical of the whole day or of the prevailing habit of life of the animal.

That it requires energy for an animal to lie down and to get up, and muscular energy to support and balance the body in a standing position, is self-evident, but as to the exact quantity of energy thus used the evidence at hand does not warrant a definite conclusion.

[4] Unpublished data of the institute.

As in the steer experiments so also with the cows a large percentage difference in heat emission per minute of standing and lying was observed. But since Armsby himself felt that the earlier correction, relating the total difference in heat emission to potential energy of body substance, was unsatisfactory, and since at present the causes for the difference in heat emission between the standing and lying postures are not fully understood, it has been thought advisable not to apply a correction for standing and lying in this experiment at this time. Subsequent experiments, not yet studied, may add sufficient light to clear up this problem.

The heat emission per minute of standing and lying has been computed from the heat as measured by the calorimeter, assuming the latent heat of water vapor to be in the same ratio as the heat of radiation and conduction for standing and lying. The heat production, as computed from heat emission by making a correction for the potential energy of gain or loss of body substance, is recorded in Table 25.

TABLE 25.—*Heat production standing and lying*

Cow No.	Period	Observed heat radiation and conduction		Latent heat of water vapor	Heat emission standing	Total production		Time lying and standing[1]	Heat production per minute	
		Standing	Lying			Standing	Lying		Standing	Lying
		Calories	*Calories*	*Calories*	*Per cent*	*Calories*	*Calories*	*Minutes*	*Calories*	*Calories*
631	I	2,983.2	4,376.4	4,487.6	40.535	4,646.9	6,817.0	982.0 458.0	10.146	6.942
	II	3,670.0	4,080.1	4,451.6	47.354	5,840.6	6,493.3	905.9 534.1	10.935	7.168
	III	4,132.1	5,133.3	4,164.7	44.597	5,895.4	7,323.8	924.7 515.3	11.441	7.920
615	I	3,771.8	4,071.5	3,870.8	48.089	5,499.2	5,936.3	843.8 596.2	9.224	7.035
	II	6,153.5	2,465.7	3,577.9	71.390	8,664.8	3,472.5	530.1 909.9	9.523	6.551
	III	6,260.9	2,610.9	3,519.2	70.571	8,491.2	3,541.0	542.9 897.1	9.465	6.522
579	I	7,282.8	2,168.0	4,204.5	77.060	10,199.4	3,036.2	445.4 994.6	10.255	6.816
	II	6,135.4	3,251.1	3,861.7	65.364	8,429.5	4,466.7	630.4 809.6	10.412	7.085

[1] The upper figure in this column should be read as minutes lying; the lower figure as minutes standing.

SUMMARY

The net energy of the feed for body increase and for milk production as determined for one cow was: For body increase, 1.212 Therms of net energy per kilogram of dry matter of feed; for milk production, 1.560 Therms not energy per kilogram of dry matter of feed—a difference of 22.32 per cent.

The percentage utilization of the metabolizable energy available for milk production ranged from 60.13 to 75.76 per cent according to the usual method, and 73.08 to 91.51 per cent according to the improved method of computing the metabolizable energy.

The difference in the net energy values of feeds for body increase and milk production indicates that milk production takes place, normally and principally, not by the transformation of body tissue but by a more direct and a less expensive process.

The computed heat production of milking cows is, on the average, between 2 and 3 per cent higher than the observed heat production

as measured by the calorimeter. This difference indicates the degree of accuracy which may be expected from metabolism experiments where only the respiration chamber and the bomb calorimeter are employed, as compared with results from the use of the respiration calorimeter. The presumption is that the direct measurement of heat production is less than the actual, and that the error involved in the indirect measurement of heat is therefore somewhat less than suggested by the foregoing figures.

Indirectly the results from one cow seem to indicate that in the last stages of gestation the animal requires approximately 2 per cent more feed for maintenance than an animal of the same weight without a developing fetus.

The apparent digestibility of the feed, in terms of energy, was the same for two of the cows, and for the third approximately 2 per cent higher.

The difference in the digestibility of the feed, in terms of energy, when computed according to the usual method, as compared with the improved method, which considers all useless matter and energy in the light of excreta, was from 16.6 to 18.8 per cent.

The percentage difference in heat emission for standing and lying as determined with cows was similar to that obtained with steers in earlier experiments.

The dry matter of the feces, notwithstanding its much higher percentage of ash and lower percentage of ether extract, has a higher energy value per gram than the dry matter of the feed.

Methane production tended conspicuously toward uniformity, and the average per day for the eight periods was 191.8 grams, or 267.6 liters of CH_4.

During the drying of the feces to the air-dry condition there is a loss of about 10 per cent of the total nitrogen; hence it is necessary to determine nitrogen in the fresh material.

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APPENDIX

TABLE I.—*Apparent digestibility of ration—Cow 631*

	Dry matter	Organic matter	Protein	Non-protein	Crude fiber	Nitrogen-free extract	Ether extract	Total nitrogen	Carbon	Energy
Period I	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Calories*
Salt	10.0									
Grain mixture	4,290.2	4,098.4	598.4	17.2	351.2	2,923.3	201.4	105.8	1,979.7	19,518.1
Alfalfa hay	2,918.2	2,680.1	429.4	78.7	805.7	1,293.3	73.0	85.4	1,335.0	12,944.5
Total eaten	7,218.4	6,778.5	1,027.8	95.9	1,156.9	4,216.6	274.4	191.2	3,314.7	32,462.6
Feces	2,314.8	2,067.0	272.7	28.0	761.2	937.5	67.6	49.6	1,087.4	10,820.6
Digested	4,903.6	4,711.5	755.1	67.9	395.7	3,279.1	206.8	141.6	2,227.3	21,642.0
Coefficient of digestibility	67.93	69.51	73.47	70.80	34.20	77.77	75.36	74.06	67.19	66.67
Period II										
Salt	10.0									
Grain mixture	4,247.1	4,060.9	591.1	20.3	350.3	2,892.0	205.1	105.2	1,956.0	19,317.4
Alfalfa hay	2,943.0	2,701.2	414.1	87.6	808.3	1,316.3	75.0	84.9	1,346.7	13,046.6
Total eaten	7,200.1	6,762.1	1,005.2	107.9	1,158.6	4,208.3	280.1	190.1	3,302.7	32,364.0
Feces	2,390.6	2,123.9	269.5	37.2	783.9	969.1	64.1	55.7	1,109.9	11,026.0
Digested	4,809.5	4,638.2	735.7	70.7	374.7	3,239.2	216.0	134.4	2,192.8	21,338.0
Coefficient of digestibility	66.80	68.59	73.19	65.52	32.34	76.97	77.12	70.70	66.39	65.93
Period III										
Salt	10.0									
Grain mixture	4,211.0	4,027.0	579.9	27.5	337.2	2,887.9	192.9	104.8	1,940.9	19,137.6
Alfalfa hay	2,962.3	2,708.1	433.2	94.1	812.0	1,290.0	78.8	89.3	1,355.8	13,154.2
Total feed offered	7,183.3	6,735.1	1,013.1	121.6	1,149.2	4,177.9	271.7	194.1	3,296.7	32,291.8
Refused feed	22.3	20.8	3.0	.5	4.0	12.5	.8	.6	10.2	100.2
Feed eaten	7,161.0	6,714.3	1,010.1	121.1	1,145.2	4,165.4	270.9	193.5	3,286.5	32,191.6
Feces	2,326.1	2,063.7	278.3	24.5	767.1	929.5	64.4	54.6	1,079.8	10,702.9
Digested	4,834.9	4,650.6	731.8	96.6	378.1	3,235.9	206.5	138.9	2,206.7	21,488.7
Coefficient of digestibility	67.52	69.26	72.45	79.77	33.02	77.69	76.23	71.78	67.14	66.75

TABLE II.—*Apparent digestibility of ration—Cow 615*

	Dry matter	Organic matter	Protein	Non-protein	Crude fiber	Nitrogen-free extract	Ether extract	Total nitrogen	Carbon	Energy
Period I	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Calories*
Salt	10.0									
Grain mixture	4,447.8	4,249.0	620.3	17.8	364.1	3,030.7	208.8	109.6	2,052.4	20,235.0
Alfalfa hay	2,993.0	2,748.8	440.4	80.8	826.3	1,326.5	74.9	87.6	1,369.2	13,276.3
Total eaten	7,450.8	6,997.8	1,060.7	98.6	1,190.4	4,357.2	283.7	197.2	3,421.6	33,511.3
Feces	2,450.3	2,204.1	294.2	24.0	786.7	1,039.1	60.2	52.2	1,150.5	11,397.3
Digested	5,000.5	4,793.7	766.5	74.6	403.7	3,318.1	223.5	145.0	2,271.1	22,114.0
Coefficient of digestibility	67.11	68.50	72.26	75.66	33.91	76.15	78.78	73.53	66.38	65.99
Period II										
Salt	10.0									
Grain mixture	4,403.1	4,210.1	612.8	21.1	363.2	2,998.2	212.7	109.1	2,027.8	20,026.9
Alfalfa hay	3,018.4	2,770.4	424.7	89.8	829.0	1,350.0	76.9	87.1	1,381.2	13,380.9
Total eaten	7,431.5	6,980.5	1,037.5	110.9	1,192.2	4,348.2	289.6	196.2	3,409.0	33,407.8
Feces	2,385.1	2,145.6	248.1	57.7	738.1	1,035.7	65.9	52.0	1,120.3	11,076.7
Digested	5,046.4	4,834.9	789.4	53.2	454.1	3,312.5	223.7	144.2	2,288.7	22,331.1
Coefficient of digestibility	67.90	69.26	76.09	47.97	38.09	76.18	77.24	73.50	67.14	66.84
Period III										
Salt	10.0									
Grain mixture	4,365.8	4,175.0	601.2	28.5	349.6	2,994.1	200.0	108.7	2,012.3	19,841.1
Alfalfa hay	3,038.2	2,777.5	444.3	96.5	832.8	1,323.0	80.8	91.6	1,390.6	13,491.2
Total eaten	7,414.0	6,952.5	1,045.5	125.0	1,182.4	4,317.1	280.8	200.3	3,402.9	33,332.3
Feces	2,404.3	2,158.5	288.4	22.3	815.1	974.6	58.3	59.7	1,125.1	11,125.3
Digested	5,009.7	4,794.0	757.1	102.7	367.3	3,342.5	222.5	140.6	2,277.8	22,207.0
Coefficient of digestibility	67.57	68.95	72.42	82.16	31.06	77.42	79.24	70.19	66.94	66.62

TABLE III.—*Apparent digestibility of ration—Cow 579*

	Dry matter	Organic matter	Protein	Non-protein	Crude fiber	Nitrogen-free extract	Ether extract	Total nitrogen	Carbon	Energy
Period I	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Calories*
Salt	10.0									
Grain mixture	4,820.6	4,609.3	670.9	23.1	397.6	3,282.5	232.8	119.4	2,220.1	21,925.9
Alfalfa hay	3,346.8	3,071.8	470.9	99.6	919.2	1,496.9	85.3	96.5	1,531.5	14,836 7
Total eaten	8,177.4	7,681.1	1,141.8	122.7	1,316.8	4,779.4	318.1	215.9	3,751.6	36,762.6
Feces	2,481.8	2,211.8	281.1	42.5	815.3	1,008.8	64.1	54.0	1,154.0	11,459.0
Digested	5,695.6	5,469.3	860.7	80.2	501.5	3,770.6	254.0	161.9	2,597.6	25,303.6
Coefficient of digestibility	69.65	71.20	75.38	65.36	38.08	78.89	79.85	74.99	69.24	68.83
Period II										
Salt	10.0									
Grain mixture	4,804.0	4,594.1	661.8	31.4	384.7	3,294.6	220.0	119.6	2,214.4	21,832.6
Alfalfa hay	3,368.7	3,079.6	492.7	107.0	923.4	1,466.9	89.6	101.6	1,541.8	14,958.8
Total eaten	8,182.7	7,673.7	1,154.5	138.4	1,308.1	4,761.5	309.6	221.2	3,756.2	36,791.4
Feces	2,529.0	2,266.3	283.2	51.7	837.1	1,031.5	62.6	56.3	1,180.7	11,655.5
Digested	5,653.7	5,407.4	871.3	86.7	471.0	3,730.0	247.0	164.9	2,575.5	25,135.9
Coefficient of digestibility	69.09	70.47	75.47	62.64	36.01	78.34	79.78	74.55	68.57	68.32

TABLE IV.—*Dry matter per day and the balance of water—Cow 631*

	Period I			Period II			Period III		
	Dry matter	Water [1]		Dry matter	Water		Dry matter	Water	
		Income	Outgo		Income	Outgo		Income	Outgo
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Alfalfa hay	2,918.2	277.0		2,943.0	201.0		2,962.3	278.0	
Grain mixture	4,290.2	635.0		4,247.1	698.0		4,211.0	693.0	
Feed residues							22.3		15.2
Water		8,025.0			23,450.0			10,355.0	
Feces	2,314.8		14,268.0	2,390.6		9,821.0	2,326.1		14,337.4
Urine	586.0			626.2			530.6		
Hair and brushings	26.3		1.9	18.7		0.9	22.4		1.4
Milk	900.7		5,543.3	125.1		907.6	None.		
Correction for CO_2:									
Milker	−14.2	20.3		−11.4	16.3		None.		
Methane	196.9			189.0			181.3		
Carbon dioxide	5,169.8			5,529.2			5,828.4		
Water vapor			8,038.3			8,050.4			7,508.2
Balance		18,894.2				5,585.4		10,536.2	
Total		27,851.5	27,851.5		24,365.3	24,365.3		21,862.2	21,862.2

[1] The balance of water has reference only to the two days spent in the respiration calorimeter.

TABLE V.—*Dry matter per day and the balance of water—Cow 615*

	Period I			Period II			Period III		
	Dry matter	Water [1]		Dry matter	Water		Dry matter	Water	
		Income	Outgo		Income	Outgo		Income	Outgo
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Alfalfa hay	2,993.0	156.0		3,018.4	204.0		3,038.2	347.0	
Grain mixture	4,447.8	652.0		4,403.1	716.0		4,365.8	699.0	
Water		11,840.0			20,130.0			8,110.0	
Feces	2,450.3		13,842.0	2,385.1		12,041.1	2,404.3		14,410.4
Urine	512.4			500.8			393.1		
Hair and brushings	22.7		1.1	20.6		1.2	18.8		1.2
Milk	1,004.6		6,036.9	1,040.7		6,139.8	1,018.8		6,234.5
Correction for CO_2:									
Milker	−19.4	27.8		−21.1	30.2		−22.5	32.2	
Methane	180.2			181.4			184.2		
Carbon dioxide	5,165.5			5,353.1			5,469.4		
Water vapor			6,647.6			6,148.5			6,088.6
Balance		13,851.8			3,250.4			17,546.5	
Total		26,527.6	26,527.6		24,330.6	24,330.6		26,734.7	26,734.7

[1] The balance of water has reference only to the two days spent in the respiration calorimeter.

TABLE VI.—*Dry matter and the balance of water—Cow 579*

	Period I			Period II		
	Dry matter	Water		Dry matter	Water	
		Income	Outgo		Income	Outgo
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Alfalfa hay	3,346.8	364.0		3,368.7	257.0	
Grain mixture	4,820.6	800.0		4,804.0	752.0	
Water		7,700.0			10,400.0	
Feces	2,481.8		14,778.6	2,529.0		14,890.0
Urine	544.6			492.6		
Hair and brushings	16.5		1.2	20.6		1.0
Milk	1,184.5		7,269.5	1,140.8		6,805.7
Correction for CO_2:						
Milker	−19.8	28.4		−23.3	33.4	
Methane	209.2			212.5		
Carbon dioxide	5,951.1			5,857.1		
Water vapor			7,616.0			6,832.1
Balance		20,772.9			17,086.4	
Total		29,665.3	29,665.3		28,528.8	28,528.8

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